ADA043468

(12)

DEVELOPMENT OF AN OPTICAL DISC RECORDER

QUARTERLY TECHNICAL REPORT

April 1 to June 30, 1977

Sponsored by

ADVANCED RESEARCH PROJECTS AGENCY

ARPA Order No. 3080
Program Code No. 6D30

Contract No. N00014-76-C-0441

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Amount of Contract: $700,719
Contract Period: 1 Oct. 1975 - 30 Sept. 1977

Prepared by

PHILIPS LABORATORIES
A Division of North American Philips Corporation
Briarcliff Manor, New York 10510

July 1977

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)

(6) DEVELOPMENT OF AN OPTICAL DISC RECORDER

5. TYPE OF REPORT & PERIOD COVERED

(9) Quarterly Technical Report,

(1) April - 30 June 1977

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)

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8. CONTRACT OR GRANT NUMBER(s)

(15) N00014-76-C-0441

9. PERFORMING ORGANIZATION NAME AND ADDRESS

PHILIPS LABORATORIES
A Division of North American Philips Corp.
Briarcliff Manor, New York 10510

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

APRA Order [redacted]-0380
Program Code No. 6D30

11. CONTROLLING OFFICE NAME AND ADDRESS

Defense Advanced Research Projects Agency
1400 Wilson Boulevard
Arlington, Virginia 22209

12. REPORT DATE

(11) July 1977

13. NUMBER OF PAGES

15

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

Office of Naval Research
800 North Quincy Street
Arlington, Virginia 22217
Code: 437

(12) 18p.

15. SECURITY CLASS. (of this report)

UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release: Distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

optical disc recorder
direct-read-after-write (DRAW)
lasers
substrate materials
recording materials
disc protective mechanism
disc
sled
air sandwich

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A recorder test fixture was assembled from previously tested components. A single-color DRAW optical system was designed, built and tested. Life testing of tellurium and bismuth films has continued with no change observed after 6000 hours at 90°C. Improved air sandwich disc configurations with metal hubs and supports were studied. A comparison of the optical disc and the best commercially available magnetic storage devices is given.

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1. SUMMARY

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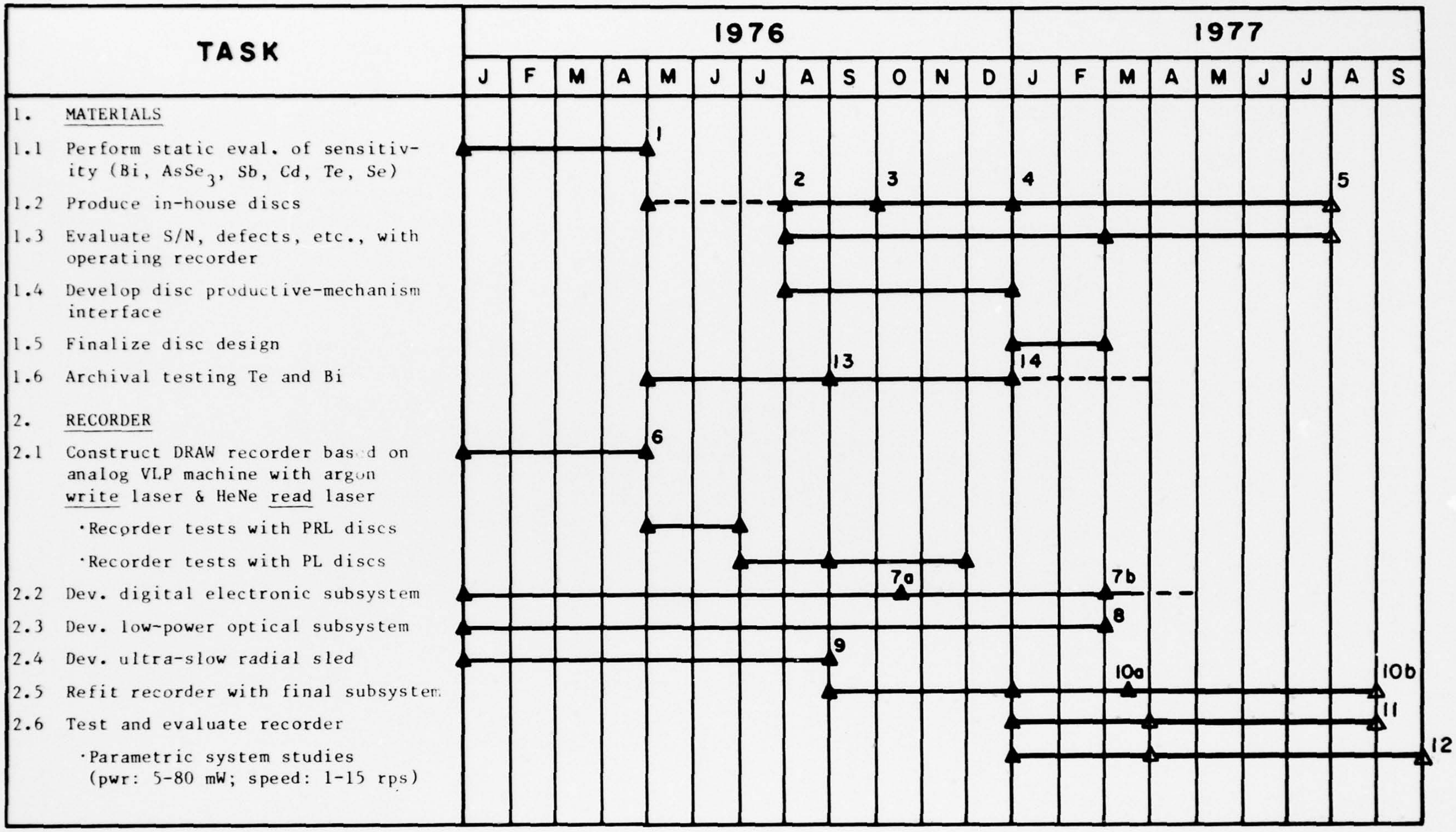
2. RESEARCH PROGRAM OBJECTIVES

The objectives of this program is to develop an optical disc recorder of digital information, with a direct-read-after-write (DRAW) capability. A storage capacity of $> 10^{10}$ bits is desired, with 4.4×10^5 bits on each of the 40,000 tracks of the disc. The desired error rate is 10^{-9} at a data rate greater than 1.33 Mbit/s. The key element in the proposed system is a recording material that can be exposed with a low-power laser (e.g., HeNe), leading to a recorder that could be manufactured for < \$10,000 and discs that would cost < \$10 in quantity.

3. SCHEDULE

The program schedule and milestones are given in Figure 1. The program completion has been rescheduled to October 1977 due to contractual changes.



▲ *Completed tasks.*

Figure 1: Program Schedule for Development of Optical Disc Recorder.

(Sht. 1 of 2)

TASK	1976												1977					
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J

PROGRAM MILESTONES

Milestone No.	Description
1	First narrowing of material choices complete.
2	Large-area deposition capability available.
3	Second narrowing of material choices complete.
4	Optimum material selected.
5	Deliverable discs available.
6	Recorder available for test.
7a	Characterization of recorder channel complete.
7b	Assy. of digital electronics subsystem complete.
8	Assy. of optical subsystem complete.
9	Assy. of improved radial sled complete.
10a	Final system assembly.
10b	System checkout complete.
11	Deliver laboratory prototype system.
12	Parametric system studies completed.
13	First lifetests on tellurium available.
14	First archival results tellurium and bismuth.

Figure 1: Program Schedule for Development of Optical Disc Recorder (Sht. 2 of 2)

4. DISCUSSION

4.1 Test Fixture

A recorder test fixture was assembled from previously* tested components (Fig. 2). The turntable consists of a Kollmorgen pancake motor fitted with an air bearing from Professional Instruments Inc. The sled is built around a Dover air bearing with a linear electric drive motor and a linear velocity transducer from Collins Corp. Recording tests with the new fixture are planned for the next quarter.

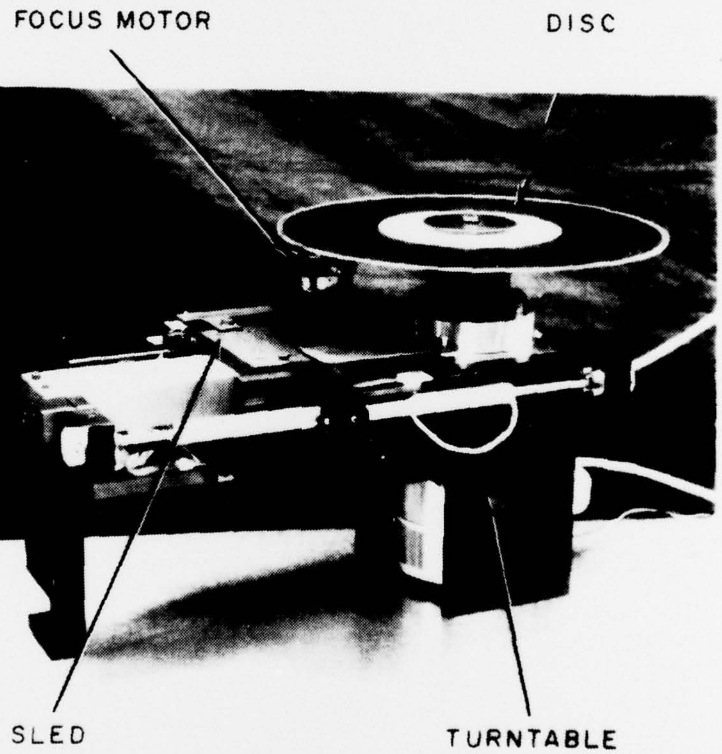


Figure 2: Recorder test fixture.

4.2 Focus Motor

An improved focus motor was constructed using new magnets. The PRL focus motor, previously selected for the DRAW recorder, was redesigned for increased sensitivity. The weight of the moving carrier was reduced from 19 grams to 11 grams, and the resistance of the coil was reduced from 12 ohms to 4 ohms. Samarium-cobalt magnets were also substituted. As a result

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* See April 1977 Quarterly Report.

of these changes, the sensitivity of the objective motor increased from 300 μm/V to 2500 μm/V measured at 30 Hz. Figure 3 shows a comparison of the motor frequency response with those previously cited in the February report. The response was free of any resonances over the frequency range of interest.

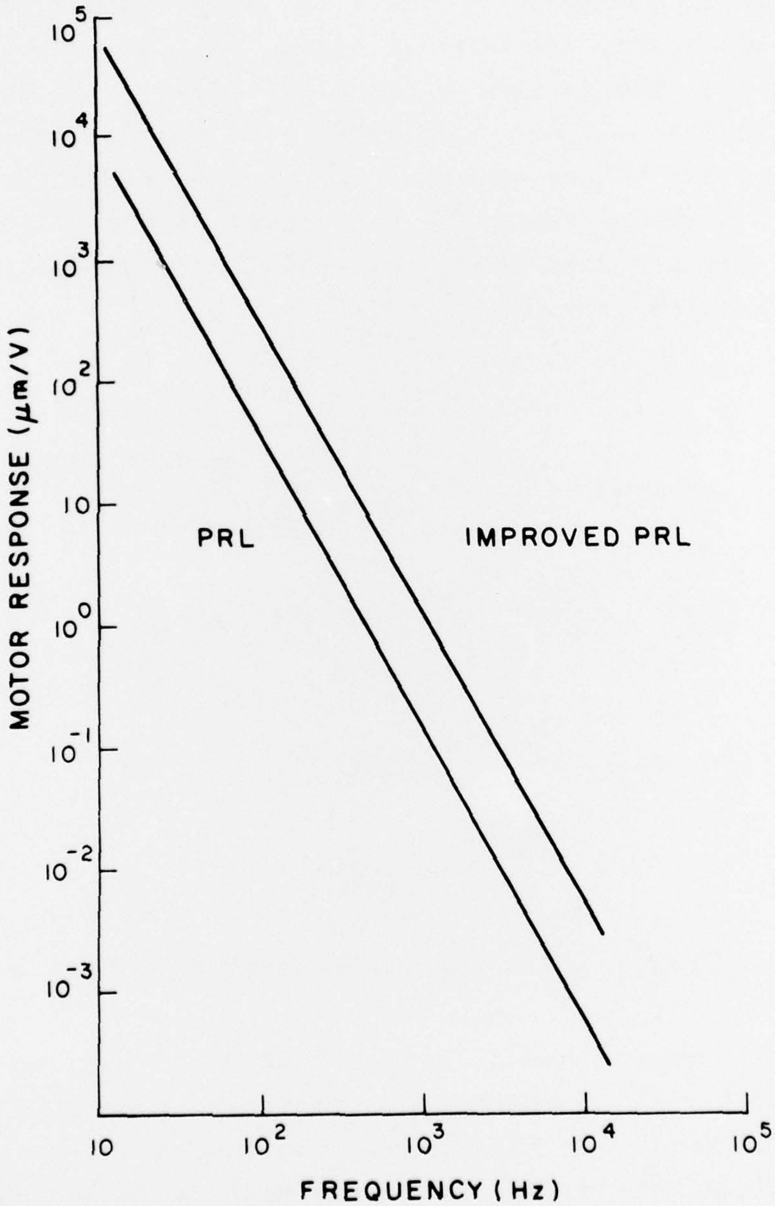


Figure 3: Frequency response of PRL and improved PRL focus motors.

4.3 Optical System

A new DRAW optical system was designed and built, and initial tests were made. A simplified schematic of the optical system is shown in Figure 4. For these first tests, an argon laser was used; however, related tests show that a Spectraphysics model 907 HeNe laser can also be used. The light output from the laser is split into two unequal beams, 90% for recording, 10% for playback. The recording beam is encoded with the information signal by a light modulator. The playback beam passes two mirrors and a beam splitter which are arranged so that the record and playback beams are recombined at the objective. The objective focusses the beams onto the information layer inside the air sandwich disc.

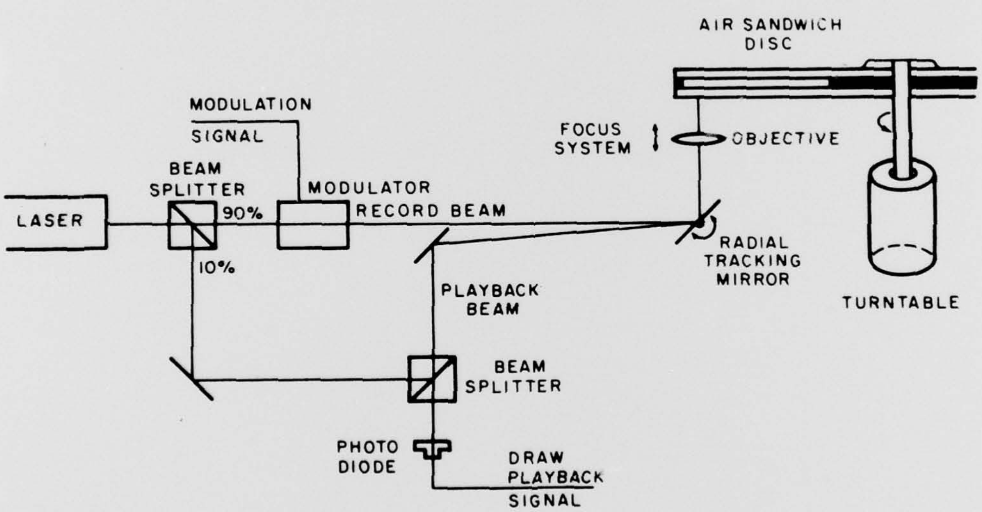


Figure 4: Simplified optical schematic of DRAW system.

Since the playback beam is slightly skew to the (recording) optical axis, the playback spot trails the recording spot by a few microns. In this manner the recorded pit is read shortly after writing (DRAW). This feature is necessary for high-quality, error-free recording. Any difference between the recorded and playback signal can be detected, and the information can be immediately re-recorded if necessary.

To record and reproduce 1 μm pit accurately, the objective must remain focused at all times to within ± 0.5 μm. This was verified experimentally. Warping of the disc can cause vertical excursions of the information surface by as much as 1 mm. Therefore, any misfocus is optically sensed and this error is minimized by an active focusing system. This focusing system has been described in previous reports.

A radial tracking mirror is necessary to follow the recorded tracks during a playback-only mode. The playback spot must follow the tracks within 0.1 μm. Since disc eccentricity can be as large as 50 μm, the radial mirror must be controlled to reduce this error to within the 0.1 μm limits. Mistracking is optically sensed,and the error controls the radial mirror to reduce the error. The tracking servo has also been described in previous reports.

During the recording operation it is not necessary to activate the radial tracking system, and the mirror is therefore held in a fixed position. In the preliminary tests a fixed mirror was used.

With an overall light transmission through the optical system of 50%, the focused power available from a HeNe laser for recording at the disc's surface is 12 mW. Based on the sensitivity of tellurium and bismuth (Fig. 5) for hole forming and the available power, a conservative disc rotation speed (240 rpm) and raw data rate (1.8 Mbit/sec) were chosen for recording. (Since there is no reason to have the recording laser power influence playback, it is anticipated that players could have higher rotation speeds and playback rates.)

The archival testing of tellurium and bismuth films has continued with no change observed after 6000 hours at 90°C (Fig. 6). Humidity stress aging was delayed due to modification of the PRL recorder and malfunction of the humidity controlled ovens. Humidity stress aging of tellurium samples and air sandwiches will begin next quarter.

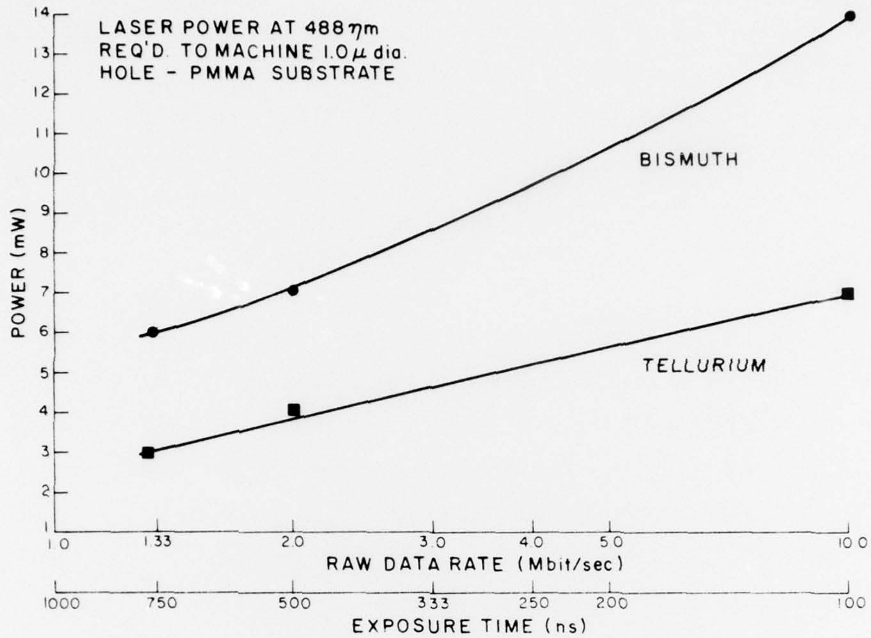


Figure 5: Laser power at 488 nm required to machine 1 μm diameter hole (PMMA substrate).

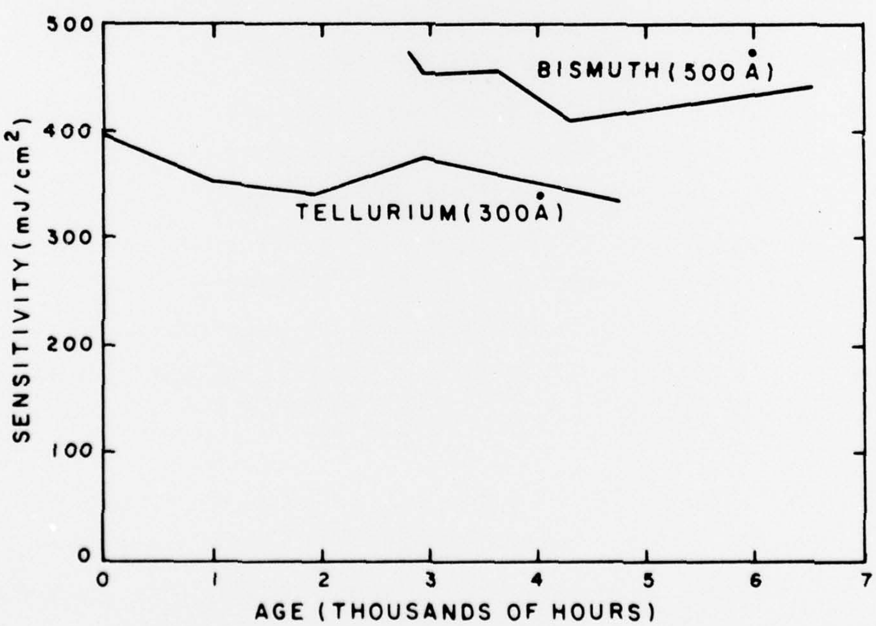


Figure 6: Hole machining vs. film age for bismuth and tellurium.

4.4 Air-Sandwich Disc Fabrication

The disc assembler previously reported (April 1977 Qtly. Rpt.) has now been tested. It works quite acceptably when bonding the sandwich components with adhesives. Some modifications were made to the machine to facilitate its use for solvent joining. Some modifications -- recommended for improving the speed of operation and operator convenience -- will be made when scheduling permits.

A technique has now been developed for solvent cementing the disc components. Obtaining a uniform bond throughout both joints of an air sandwich is particularly difficult with solvents since they tend to wick onto undesired surfaces of the disc and assembly fixture. However, the joints that result from the use of certain solvents are extremely strong and clear. The technique developed is illustrated in Figure 7.

The inner and outer spacers are held flat and concentric by means of a guide plate (Fig. 7a). A puddle of solvent is placed on the inner spacer, and a tellurium-coated substrate is lowered into contact with the puddle. The substrate is held with a vacuum plate and bulged out slightly by means of a spring-loaded plunger protruding through the center of the plate. As the bulge contacts the puddle, a meniscus is formed which is concentric with the axis of the disc. Further clamping of the guide and vacuum plates flattens the bulge, thereby spreading the solvent to the outer edge of the spacer. Solvent is then wicked in between the outer spacer and substrate by moving a hypodermic needle around the outer edge of the disc (Fig. 7b). The outside diameter of the outer standoff is 1 to 3 millimeters larger than that of the substrate. The step formed, by the difference in diameters, provides a guide for the needle and prevents solvent from wicking between the guide plate and the spacer. The resulting assembly is then turned over and held down to the lower vacuum plate. The second substrate is cemented into place by repeating the above procedure (Fig. 7c).

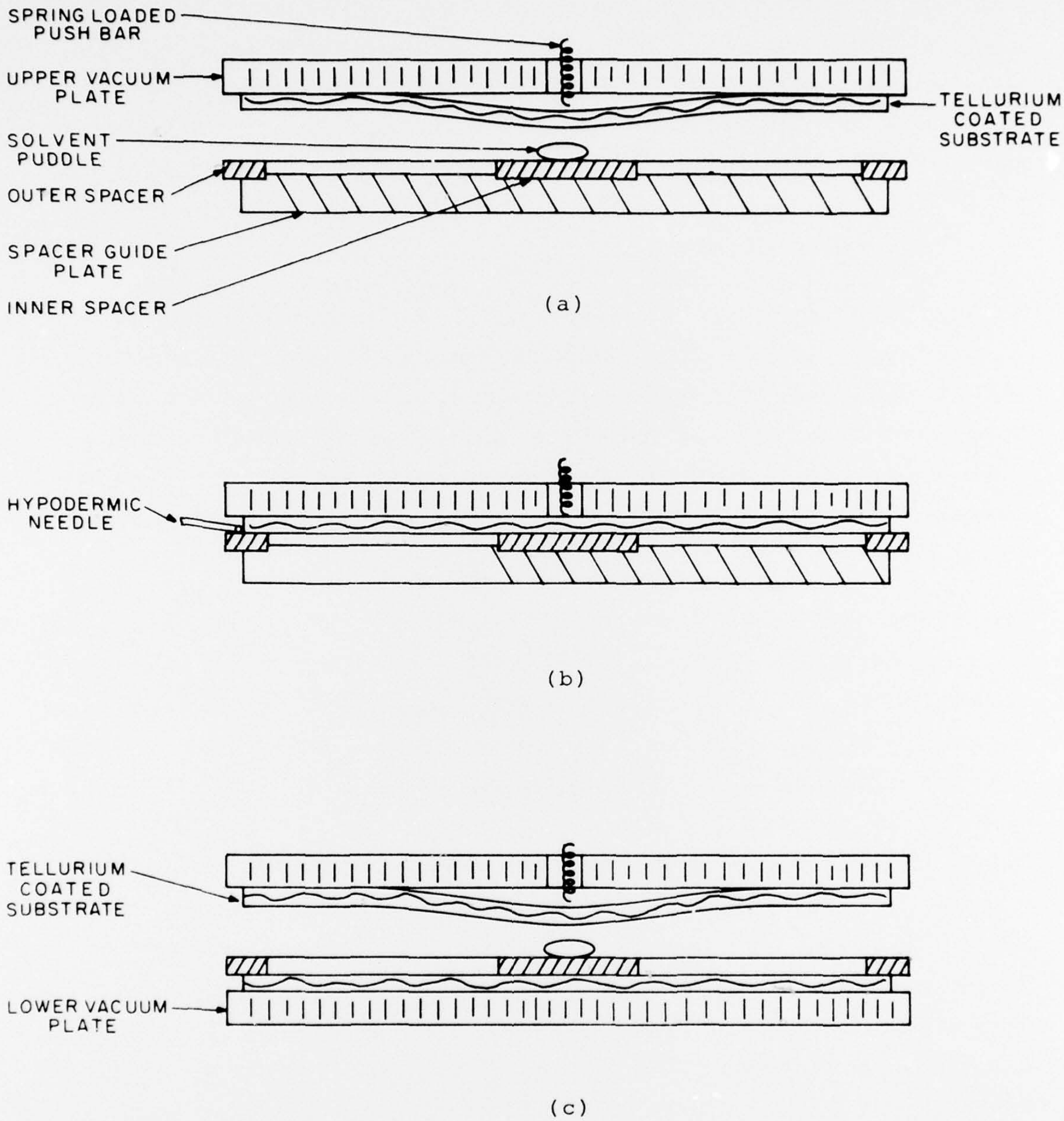


Figure 7: Solvent cementing technique for air sandwich discs.

To date, the best solvent tested is the unpolymerized methyl-methocrylate monomers from which the Glasflex Electroglas substrate is made. The resulting joint is very clear and at least as strong as the substrates.

4.5 Alternate Air Sandwich Structures

A new type of disc hub is being constructed to strenghten the disc structure. The basic idea is to replace the entire label area of the disc with a steel plate which contains the 35 mm spindle hole (Fig. 8). The plate also serves as the inner spacer. Such a design has many potential advantages.

Disc assembly is particularly simple. A low viscosity cyanoacrylate adhesive such as Permabond 101 readily wicks into the gaps between the plate and the substrates. The plate, with its prefinished spindle hole, can be bonded in place so as to locate the center of the spindle hole on the mass center of the final assembly.

All the plate dimensions -- spindle hole, spindle hole position, thickness, flatness, and outer diameter -- can be controlled much more precisely with a metal rather than a plastic center. Therefore, within the tolerance of the plate-thickness variations

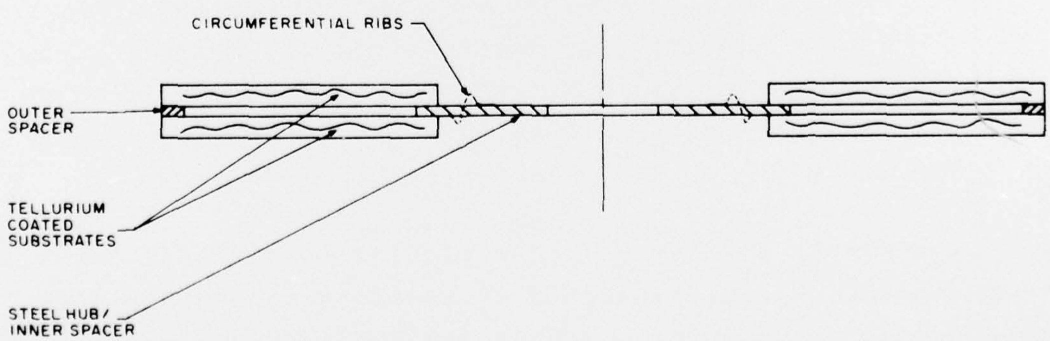


Figure 8: Alternate hub configuration.

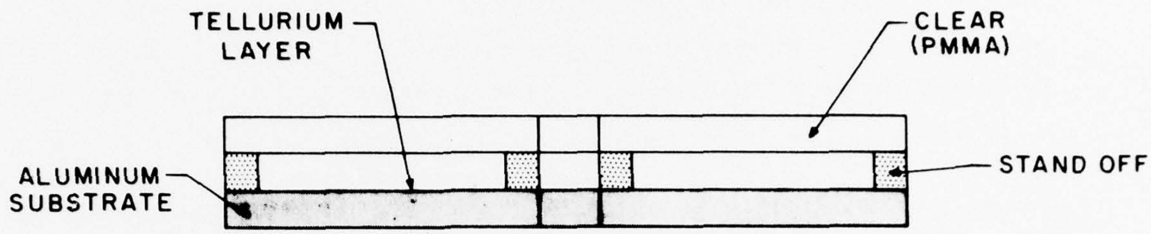
(typically less than $\pm$ 25 μm), the location of the disc parallel to the axis of the turntable is referenced to the nominal film plane and thereby becomes nearly independent of variations in substrate thickness (typically $\pm$ 125 μm). And, insofar as the flatness of the disc is determined by the flatness and stiffness of the hub, it should be possible to make the disc flatter. For example, the flatness and stiffness of a metal plate can be significantly increased by stamping circumferential ribs into it (Fig. 8). One would also expect that the disc would be more dimensionally stable -- when subjected to temperature and humidity variations -- than one with a plastic hub.

Finally, a steel hub offers the opportunity to clamp the disc magnetically.

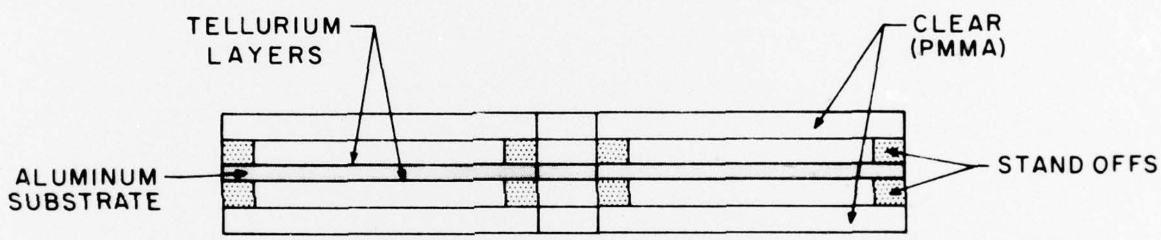
Several discs are presently being made with 1/2 mm thick cold rolled steel hubs. Circumferential ribs have been pressed into the hubs. Some of the discs will be evaluated immediately, and the remainder will be subjected to elevated temperature and humidity environments. In order to prevent corrosion, the hubs have been plated. Both gold and nickel plating will be evaluated.

We have also begun a search for a potentially more stable substrate material than PMMA. Corning Glass has been contacted about the availability of toughened glass with the required specifications. Results are not yet in. In addition, experiments will be conducted shortly to establish the feasibility of using pre-treated aluminum as a substrate for tellurium. Aluminum discs are commonly prepared with high quality surfaces by both the audio and magnetic disc industries.

Two air sandwich configurations employing an aluminum substrate are possible. A single-sided air sandwich with an aluminum substrate is shown in Figure 9a. The substrate is precoated with



(a) Single sided.



(b) Double sided.

Figure 9: Air sandwich configuration with aluminum substrate.

a low-thermal loss layer before depositing the tellurium film. The second half of the sandwich is a clear disc of PMMA. Recording and playback of information on the tellurium film is done through the clear PMMA cover disc. This configuration would appear to require an objective with a larger air working distance because of the air cavity; however, the greatly improved flatness characteristics of the aluminum disc are expected to compensate for this by reducing the focus travel requirements of the objective. Therefore, the same objective should be suitable for either conventional PMMA or aluminum air sandwich structures.

A double-sided air sandwich structure with an aluminum center substrate is shown in Figure 9b. Tellurium films would be deposited on both sides of the precoated aluminum disc. Recording and playback is again through a clear protective disc as in Figure 9a.

The aluminum air sandwich structures are being considered only as an alternative to the conventional PMMA structures. The all-PMMA structures still remain the preferred configuration and will continue as the main effort at PL.

4.6 Comparison with Magnetic Storage

A comparison of the best commercially available magnetic storage devices and the optical disc is given in Table I. PL does not claim or even infer that the optical disc can replace magnetic storage media. In many applications where erasure is necessary, the optical disc is unsuitable.

However, optical recording does offer some potential advantages, viz., a low-cost and efficient storage media, and improved archival properties. The media cost is estimated at 5×10^{-5} cent/bit. The volumetric storage efficiency of the optical disc is 48 times better than 6250 bpi magnetic tape. The cost and size advantages are primarily due to the very high storage density of optical recording (2×10^{8} bits/sq. inch).

5. PLANS

a. Test new recorder fixture.

b. Analyze playback of digital information from air sandwich disc.

c. Begin humidity testing of tellurium.

d. Study alternative air sandwich structures.

TABLE I
<u>CHARACTERISTICS OF MASS STORAGE DEVICES</u>

DEVICE	CAPACITY (bits)	ACCESS TIME (ms)	DATA RATE (Mbit/sec)	HARDWARE COST	MEDIA COST ($)	COST/BIT (cents)	ARCHIVAL LIFE
Magnetic Disc[3] IBM 3340	$5.5x10^{8}$	35	7.0	$20,000	$2,200 disc pack	$4x10^{-4}$	2-3 yrs?
6250 B.P.I. Tape IBM 3420	$7.4x10^{8}$	60,000	3.7	$30,600	$16.50 2400' reel	$2.2x10^{-6}$	1-2 yrs.
Mass Storage System IBM 3850	$3.7x10^{12}$	16,000	7	$2,400,000	$188,000 9400 cartridges @ $20 ea.	$5x10^{-6}$	1-2 yrs.
Philips Labs Optical Disc	$2x10^{10}$	500	2-10	$10,000	$10	$5x10^{-8}$	>10 yrs.

Notes: 1. Performance and costs of IBM equipment from "DATAPRO".

2. Performance and costs of Optical Disc Equipment are best estimates only.

3. Largest drive with removable disc pack.